Treatment Facility F

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Introduction

The treatment facility used by the Dynamic Underground Stripping project was originally designed as a vacuum enhanced pump and treat facility to remediate a gasoline spill at the Lawrence Livermore National Laboratory. Gasoline contaminated ground water and vapor were to be extracted using traditional pump and treat methods. The facility, designated Treatment Facility F (TFF), was designed to operate for 30 years although complete remediation of the site by pump and treat methods was calculated to take in excess of 200 years. Modifications were made to the treatment facility to handle the elevated temperatures associated with Dynamic Stripping and the remediation effort began.

During the Dynamic Stripping operation at the gas pad, approximately 42 x 10^6 liters (11 million gallons) of water was pumped from the ground. Using a volume-weighted average hydrocarbon concentration of 36,000 ppb, approximately 2,000 liters (530 gallons) of liquid-volume-equivalent gasoline was removed. During the same time, approximately 850 x 10^6 cubic liters (30x 10^6 standard cubic feet) of vapor was extracted with a volume-weighted hydrocarbon concentration of about 5,000 ppmv. Liquid-volume-equivalent gasoline removed from the vapor stream amounted to about 23,000 liters (6,000 gallons) burned and 4,500 liters (1,200 gallons) condensed and collected for a total vapor stream removal of about 27,000 liters (7,200 gallons).

Treatment Facility F

TFF was designed to treat ambient temperature liquid and vapor extracted from the ground. The liquid stream was treated by separation of free product, oxidation of gasoline dissolved in water, and finally air stripping as a polishing stage. The vapor stream was initially treated by carbon absorption but later, after hydrocarbon concentrations increased due to steam injectio burned in an internal combustion engine. The entire treatment facility was monitored and controlled by an IBM compatible, 486 microprocessor-based computer. The computer was capable of logging many treatment facility operational parameters such as water levels, temperatures and equipment status. Operational parameters falling outside prescribed limits would cause an alarm to alert operators and if necessary could shut down the entire treatment facility. Frequently, alarms were the result of sensors that were covered by scale or dirt and in some cases material failures that were the result of elevated temperature and chemical degradation. Frequent cleaning and maintenance of sensing equipment was necessary to minimize nuisance alarms. Diagrams of major treatment system components are shown in Figures 1 and 2.

Liquid Stream Treatment

The liquid phase treatment system has a design capacity of 380 liters/m (100gpm). Liquid phase treatment consists of:

1. Separation of free phase gasoline from extracted ground water in an oil water separator (OWS),

2. Destruction of gasoline dissolved in water via ultra-violet/hydrogen peroxide oxidation (UV/H_2O_2), and

3. A final polishing stage of air sparging with off-gas treatment through granular activated carbon (GAC) to remove hydrocarbon residuals.

Ground water was pumped from the extraction wells with Ejector Systems pneumatic pumps placed approximately 42 meters (138 feet) below ground surface. The water table at the site was at approximately 30 meters (100 feet). Each pump had a maximum capacity of 190 liters/m (50gpm). During actual operation we pumped a combined average of 230 liters/m (60 gpm) from the two pumps. Higher rates were not possible because of effluent water discharge limits set by the regulatory agencies. Pneumatic pumps were selected primarily because of the explosion hazard of gasoline vapors and secondly to reduce emulsification of the pumped liquid. The pumps, with controllers, were approximately $25,000 each. Air was supplied by a Kobelco 60 HP, two-stage, oil-free, rotary screw air compressor (Model KNW O-B/H, $36,000).

The pumped ground water was at a maximum temperature of 100°C (212°F). It passed through an ambient air heat exchanger (built by Chiller Manufacturing Co., $27,000) and cooled to about 40°C (110°F). Cooling water for both heat exchangers used on site (vapor stream and liquid stream) was cooled by a Marley cooling tower (model No. NC3012).

After the ground water effluent was cooled, it was piped to two oil/water separators (Megator S4A1, $9,660 each) plumbed in parallel. Each separator was capable of processing 228 liters/m (60 gpm) of liquid. Even though free product had been observed in monitoring wells prior to the start of Dynamic Stripping, only about 700 liters (180 gal) of free product was skimmed from the ground water out of a total recovered gasoline volume of over 27,000 liters (7,200 gal).

After leaving the separators, the gasoline contaminated water was passed through a Peroxidation Systems, Inc., ultraviolet light-hydrogen peroxide (UV/H_2O_2) oxidation system (model LBV-60).

The UV/H_2O_2 oxidation system did not work as efficiently as anticipated during and immediately after steam injection. We hypothesized that the UV light may have been absorbed by aqueous inorganic compounds mixed with the water, reducing its destruction efficiency. A second possibility is that free product had gotten past the oil/water separators, remained trapped inside the LBV-60 and continually dissolved into the effluent stream as it passed through the machine. During maintenance on the LBV-60, some free product was found trapped in cavities inside the machine.

Effluent from the LBV-60 passed through air sparging tanks for final treatment to achieve discharge standards in treated water. Air sparging removed single-bonded carbon VOC's such as chloroform, carbon tetrachloride and ethylene

Figure 1. Treatment Facility F as originally designed with self-regenerating carbon adsorption system to treat contaminated vapors.

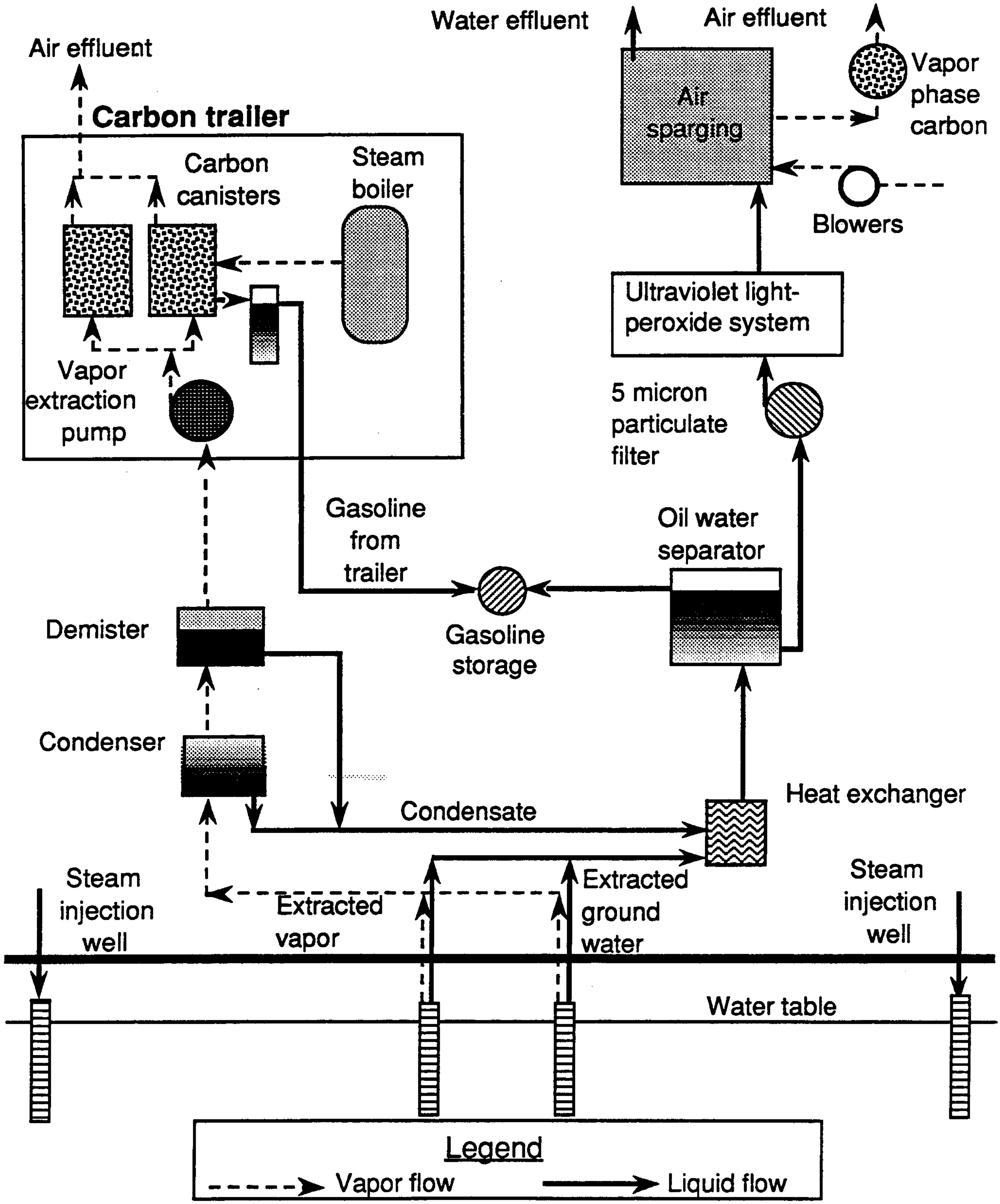
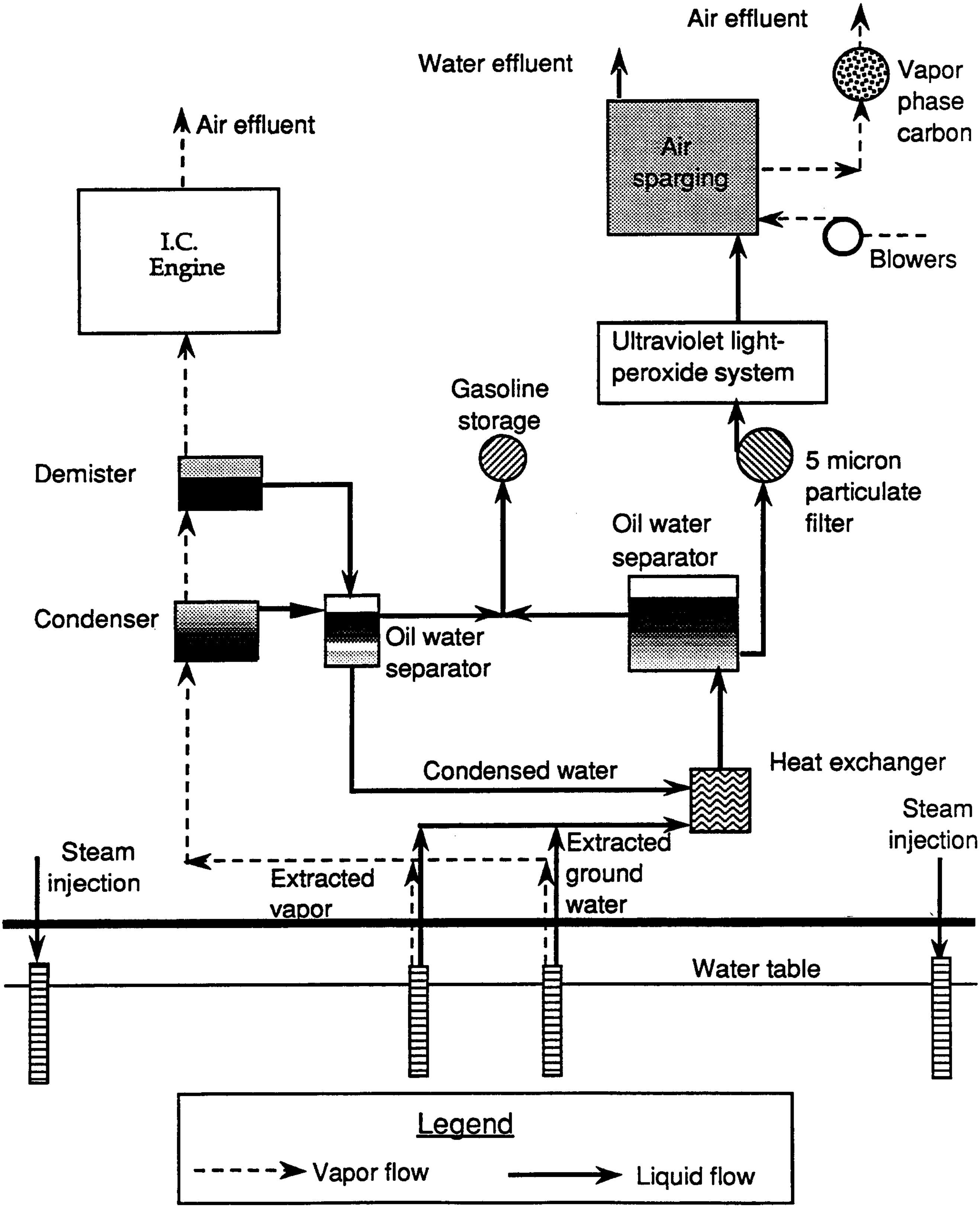


Figure 2. Treatment Facility F modified by the addition of internal combustion engines replacing the self-regenerating carbon adsorption system to treat contaminated vapors.



dibromide that are poorly degraded by the UV/H_2O_2 process. We used six Fuji VFC903A-7W blowers ($2,500 each with silencers) to provide air for the tanks. Granular activated carbon (GAC) was used to remove volatile organic components (VOC's) from the effluent air of the sparging tanks. The Bay Area Air Quality Management District (BAAQMD) allowed 10 ppmv total hydrocarbon concentration in discharged air. The GAC was changed as necessary to keep below the 10 ppmv discharge limit. After sparging the water was discharged to the sanitary sewer.

Vapor Stream Treatment

The vapor treatment system extracted vapors from the same centrally located extraction wells as the ground water treatment system. The wells were screened in the vadose zone 18 to 27 meters (60 to 90 feet) below the surface. During the first steam injection pass, vapors were pulled from the wells through a self-regenerating granular activated carbon system to remove VOC's. Dual 340 kg (750 lb) carbon canisters were housed inside a trailer (built by Continental Recovery Systems). The portable vapor treatment system was designed for a 11,000 liters/m (400 cfm) vapor extraction rate and was capable of removing approximately 110 liters/d (30 gpd) of gasoline. The trailer also contained the vacuum pump providing vacuum for the wells, an oil/water separator (OWS) and a small boiler used to regenerate the carbon beds. The 25 hp vacuum pump was capable of 8,500 to 9,200 liters/m (300 to 325 cfm) at 10 to 12 inches of mercury at the wellheads. During extraction operations, one carbon bed was active while the other saturated bed was being desorbed using the unit's 100 kW (400,000 BTU/h) boiler. Regenerate consisting of steam and gasoline vapor was condensed in a small flat plate heat exchanger and separated in the OWS. The separator was capable of collecting about 100 liters (30 gal) of gasoline per day.

For ambient temperature systems the carbon trailer was a cost effective means of removing contaminants relative to typical GAC systems because the carbon beds were self-regenerating. However, for the high recovery rate experienced with elevated subsurface temperatures, the carbon trailer was undersized. Total hydrocarbon concentrations in the vapor stream reached as high as 100,000 ppmv after the first steam injection phase. Vapor stream hydrocarbon removal accounted for approximately 95% of the total hydrocarbons removed at the site during the Dynamic Stripping project. Greater treatment capacity was necessary to handle the high gasoline concentrations in the vapor stream.

To handle the unexpected vapor stream hydrocarbon concentrations we installed a VR Systems internal combustion engine (ICE) unit capable of extracting and burning as much as 600 liters of hydrocarbons per day (150 gpd). The stand-alone unit consists of two microprocessor controlled, Ford 7.5 liter (460 CID) industrial engines. Dilution air and natural gas were added to the vapor extracted from the wells to maintain stoichiometric combustion. Even though the ICE's vapor treatment capacity was five times greater than the carbon trailer, we could have used more capacity to handle peak concentrations.

Since the extracted vapor was about 90°C (195°F) during and after steam injection, the vapor was cooled prior to entering the carbon trailer and IC engines by a flat plate heat exchanger with 13°C, 1,500 liter/m (56°F, 400 gpm) coolant water flow . Water for the flat plate exchanger was cooled by the Marley cooling tower. During the first steam injection pass, condensate from the vapor stream was piped directly into the water effluent stream prior to entering the OWS. During the second steam injection pass, vapor stream condensate was transfered to a separate OWS, after which the effluent water was piped to the UV/H_2O_2 system. The maximum gasoline skimming rate for the vapor stream separator (Megator model S2A1) was about 75 liters (20 gal) per day. Using a separate vapor stream OWS greatly simplified the analysis of how much contaminant was being removed in each of the two conaminant streams.

The flow measurement of the vapor stream was the most critical measurement involved in estimating gasoline removal. Two types of measurements were made of vapor stream flow rate to reduce uncertainty. The first was a Meriam Laminar Element flow sensor and the second a Dwyer Pitot-type differential pressure sensor. The two devices agreed to within ±10%, indicating that the readings were reasonably accurate.

TFF Operation

Treatment Facility F (TFF) operations were started after the electrical preheating phase of dynamic stripping was completed in January of 1993. It was operated through 2 phases of steam injection and one post dynamic stripping phase.

The "first pass" of steam injection began on February 4, 1993 and ran continuously through March 12, 1993. TFF was operated 24 hours per day throughout this period. The first two weeks of TFF operation could be characterized as a shakedown period during which bugs and problems with the system were identified and fixed. Steam injection rates were constrained by the limited readiness of the treatment facility. By the third week of operation the facility settled into a more routine mode of operation that continued until the first pass was completed.

The treatment facility was shut down from March 15 through May 23 for modifications and maintenance. The internal combustion engine was added to the treatment system as well as other minor system modifications to handle the unexpectedly high gasoline removal rate. Other maintenance of equipment such as pumps, compressors, valves and process piping was also completed during this period.

On May 24 the second and final steam injection pass started. Although steam was injected intermittently (nominally 5 days on and 5 days off) the treatment facility ran 24 hours per day until July 9th. After July 9th, TFF was operated during normal business hours 5 days per week through September.

The treatment facility was operated 24 hours per day during a post-dynamic stripping phase called the Accelerated Removal and Validation project (ARV). ARV ran from October 4, 1993 to December 13, 1993, interrupting continuous operation on only two weekends. Although no steam injection occurred during the ARV phase, the treatment facility was operated continuously to maintain ground water draw down. By maintaining maximum draw down, we were able to expose normally saturated sediments to vapor flow and maximize hydrocarbon removal while the ground was still hot. The ARV project also provided the opportunity to test some system optimization strategies while taking advantage of the heated subsurface and enhanced removal rate. Table 1 summarizes Treatment Facility F's 1993 operations.

To accurately account for the gasoline removed, a very intense level of treatment system monitoring was required. This included daily and in some instances twice daily chemical analysis of vapor and water samples collected at various points throughout the treatment facility. It also required hourly recording of such operational parameters such as flow rates, temperatures, pressures, gasoline accumulated, etc.

Regulatory Permitting

The boiler used to generate steam for injection into the ground was a natural gas fired, 32 x 10^6 BTU/h input unit equipped with Best Available Control Technology (BACT) to reduce stack emissions. BACT refers to a boiler equipped with a low NO_x burner and flue gas recirculation. Under guidelines set forth in November of 1991 by the Bay Area Air Quality Management District (BAAQMD), NO_x emissions were limited to 40 ppm at 3% O_2. Under normal circumstances, the BAAQMD would require a discharge permit for the boiler emissions. However, since the steam was needed for a relatively short period of time for a research project, we successfully petitioned the air board for a research exemption. The air board allowed LLNL to operate the boiler 24 hours per day for 60 days without purchasing the right to discharge an estimated 1,045 kg (2,200 pounds total, 1.6 lbs/h) of NO_x.

The BAAQMD did require permits for three other treatment facility operations. Those were the ground water treatment system air stripping discharge, the carbon trailer self-regenerating carbon system, and the exhaust from the internal combustion engine. Requirements are summarized in Table 2. Each of these operations were restricted as to hydrocarbon concentration, mass discharge limits for certain toxic compounds such as benzene, destruction efficiencies, monitoring requirements and record keeping. A daily log book was maintained that contained hours of operation, analytic results and frequency of carbon replacement for the air stripping discharge. The site was also subject to unannounced inspections of all facilities including storage tanks, process piping, equipment and records.

The treatment facility was intended to achieve NPDES discharge limits (Natural receiving water discharge limits) as set by the federal EPA through the Bay Area Regional Water Quality Control Board (RWQCB). However, some compounds were not efficiently destroyed by the UV/H_2O_2 system or stripped by air sparging system. To complete steam injection by the June 30, 1993 boiler exemption expiration date, we opted to discharge the treated water to the sanitary sewer rather than attempt to improve the facility's performance to meet NPDES limits. The Livermore Water Reclamation Plant (LWRP) regulated water discharges to the sanitary sewer at the site. LWRP restricted us to a maximum discharge rate of 285 liters/m (75 gpm) and an average discharge rate of 190 liters/m (50 gpm). Sampling was required to determine concentrations of BTEX (benzene, toluene, ethyl benzene, total xylenes), toxic organics, metals, and cyanide. During 1993 approximately 42 x 10^6 liters (11 x 10^6 gallons) of water was pumped from the ground and discharged to the sanitary sewer. Based upon chemical sampling of the water prior to discharge, less than 3 liters (0.8 gallons) of gasoline were discharged to the sewer. A summary of LWRP compliance requirements are presented in Table 3.

Table 2. Bay Area Air Quality Management District regulatory compliance requirements for air discharges at Treatment Facility F.

Sample Point	Analyte	Frequency	Discharge Limit
Air Stripping Discharge	TH	5/Week	10 ppmv
Carbon Trailer Discharge	TH	5/Week	10 ppmv
IC Engine Discharge	TH	5/Week	See below
Site Wide Benzene Discharge	Benzene	Monthly	0.8 kg/d (1.8 lb/d)

TH=Total Hydrocarbons.
Site wide benzene discharge limit (1.8 lb/d) averaged over any 365 day period.
Non-methane destruction efficiency of IC Engine required to be >98.5%.

Table 3. Livermore Water Reclamation Plant regulatory compliance requirements for water discharges at Treatment Facility F.

Analyte	Frequency	Discharge Limit
BTEX	Quarterly	250 ppb
Toxic Organics	Annually	1,000 ppb
Metals	Annually	See List Below
Cyanide	Annually	40 ppb

BTEX=benzene, toluene, ethyl benzene, total x ylenes
Metals Discharge Limits in ppb: As: 60; Cd: 140; Cu: 1,000; Total Cr: 620; Pb: 200; Hg: 10; Ni: 610; Ag: 200; Zn: 3,000

Table 1. Treatment Facility F 1993 performance summary.

Month	Hydrocarbon Concentrations (a)		Volumes Pumped		Gasoline Removal (gals)			
	Water (ppb)	Vapor (ppmv)	Water (gals)	Vapor (cubic ft)	Water	Condensed from Vapor	Vapor	Totals
January	<————		System Off		————>			
February	54,000	2,300	1,780,000	9,900,000	124	b	840	964
March	81,000	2,200	1,040,000	5,200,000	110	b	430	540
April	<————		System Off		————>			
May	37,000	14,900	186,000	770,000	9	335	428	772
June	25,000	10,200	2,400,000	5,700,000	79	569	2158	2,806
July	19,000	9,100	900,000	2,000,000	23	103	679	804
August	21,000	11,000	122,000	600,000	3	80	246	330
September	18,000	5,500	174,000	840,000	4	19	172	195
October	12,000	4,100	2,000,000	4,200,000	32	65	649	746
November	9,000	1,400	1,600,000	2,400,000	19	49	127	195
December	9,000	1,300	600,000	1,200,000	7	5	59	71
Total			11,000,000	33,000,000	400	1,200	5,800	7,400

Notes: (a)—Concentrations are flow-weighted averages

(b)—Condensed gasoline routed to water system during First Steam Pass, February and March.